

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Small pitch pixel detector for the CMS phase II upgrade

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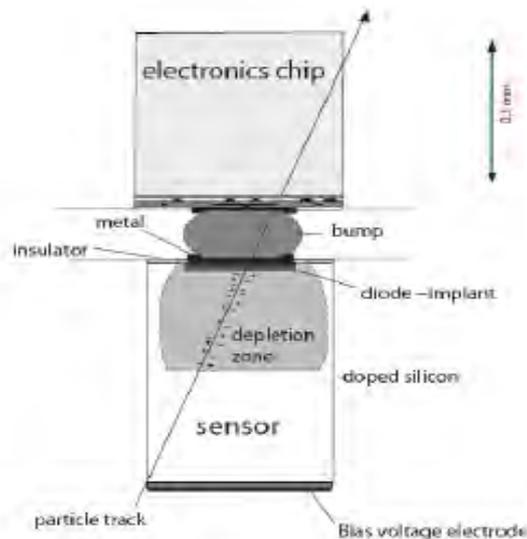
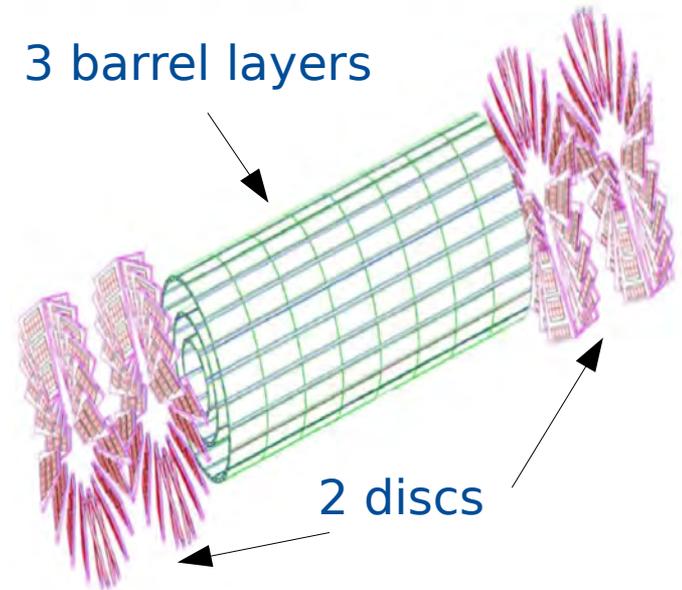
Final Reports

22 September 2015



CMS Silicon Pixel Detector

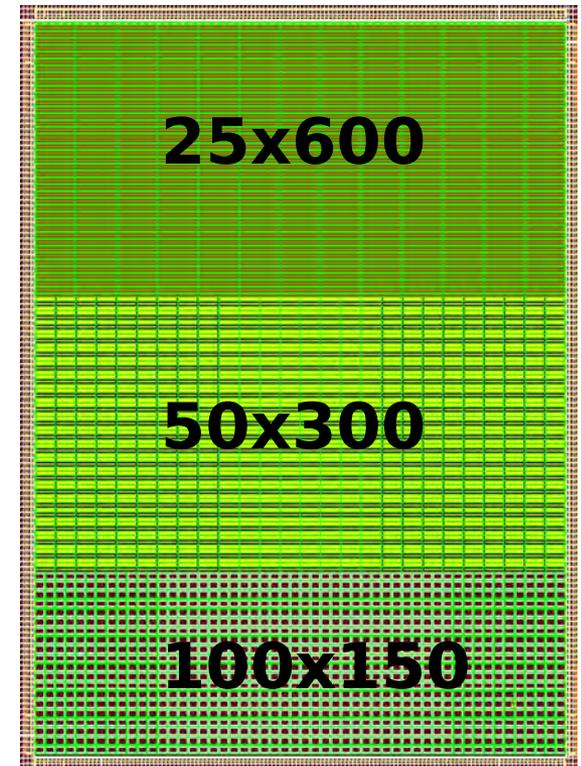
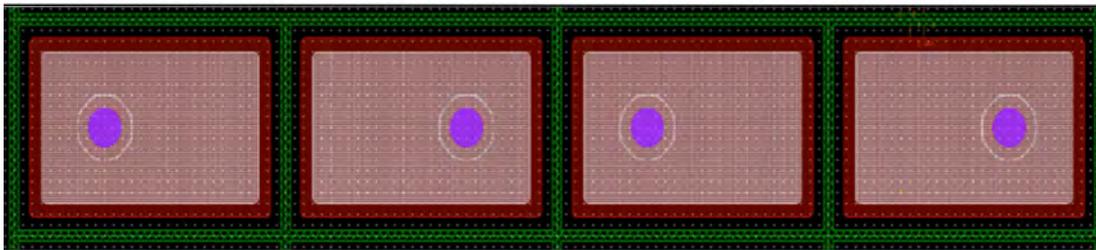
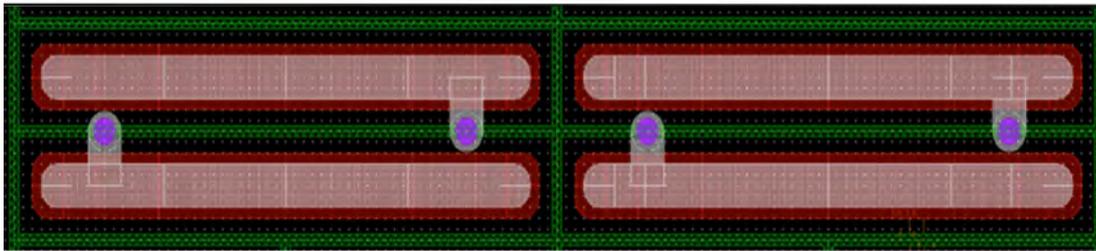
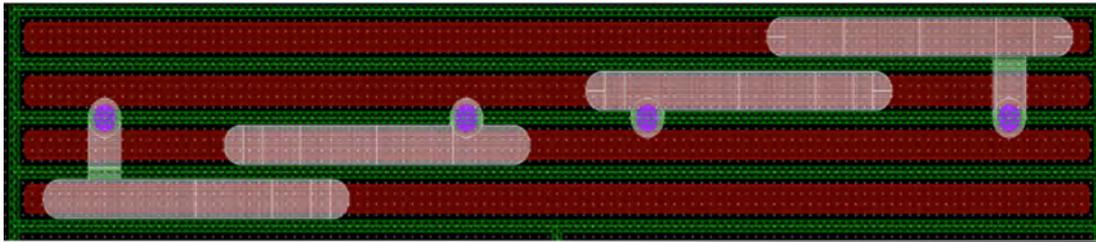
- It is the innermost and most precise part of the CMS tracking system.
- 1 barrel detector module is composed of 16 Read Out Chips (ROCs).
- 1 ROC has 4160 pixels.
- Pixels of standard dimension ($100 \times 150 \mu\text{m}^2$) are arranged in 52 columns and 80 rows



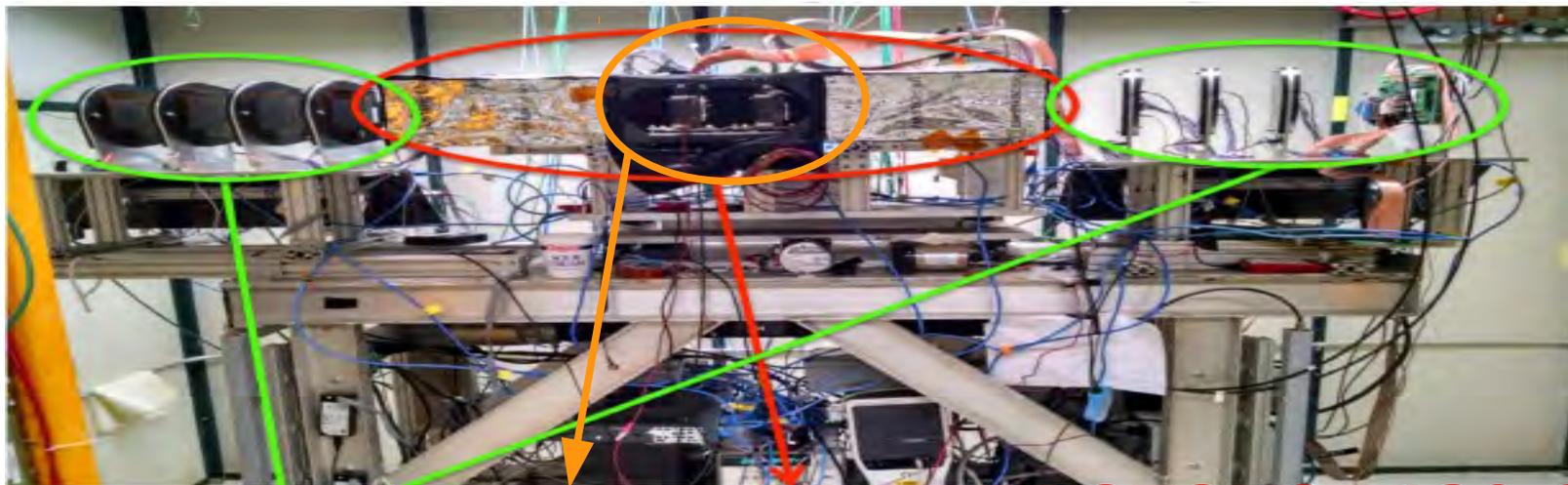
- Each pixel is bump bonded to the ROC

Small Pitch Prototype Design

- Maintained the same pixel area $100 \times 150 \mu\text{m}^2$ that is implemented in the Phase-I design
- Single ROC sensors split in 3 regions with 3 different pitches



June Test beam and data acquisition

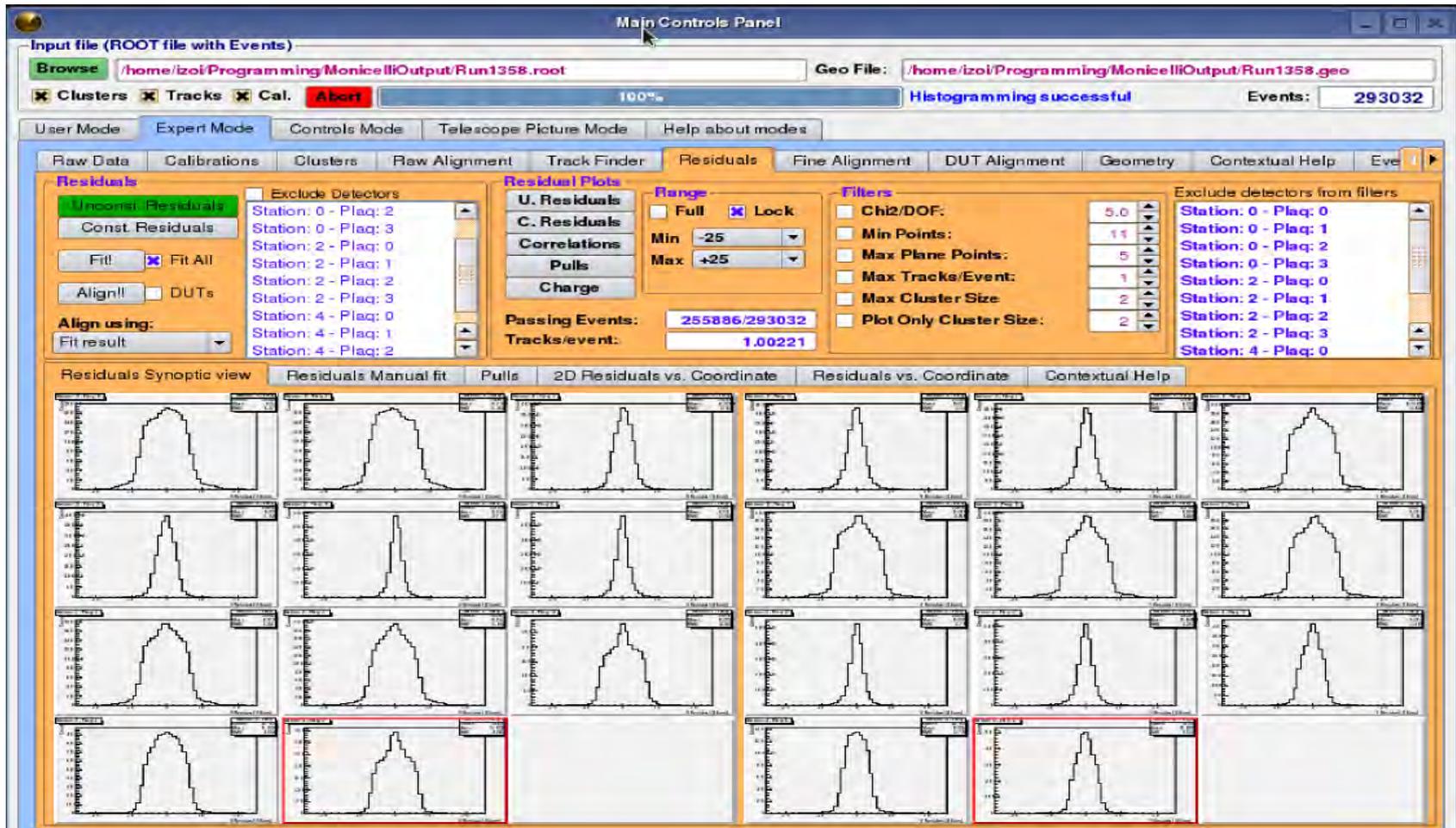


Strip telescope **DUTs** Pixel Telescope **PROTONS@120 GeV**

- Hits in the pixel detectors are grouped together according to the trigger number.
- The data acquired are first analyzed by a tracking program (Monicelli) that aligns the detectors and reconstructs tracks.
- Then another program (Chewie) is used to analyze the reconstructed tracks.

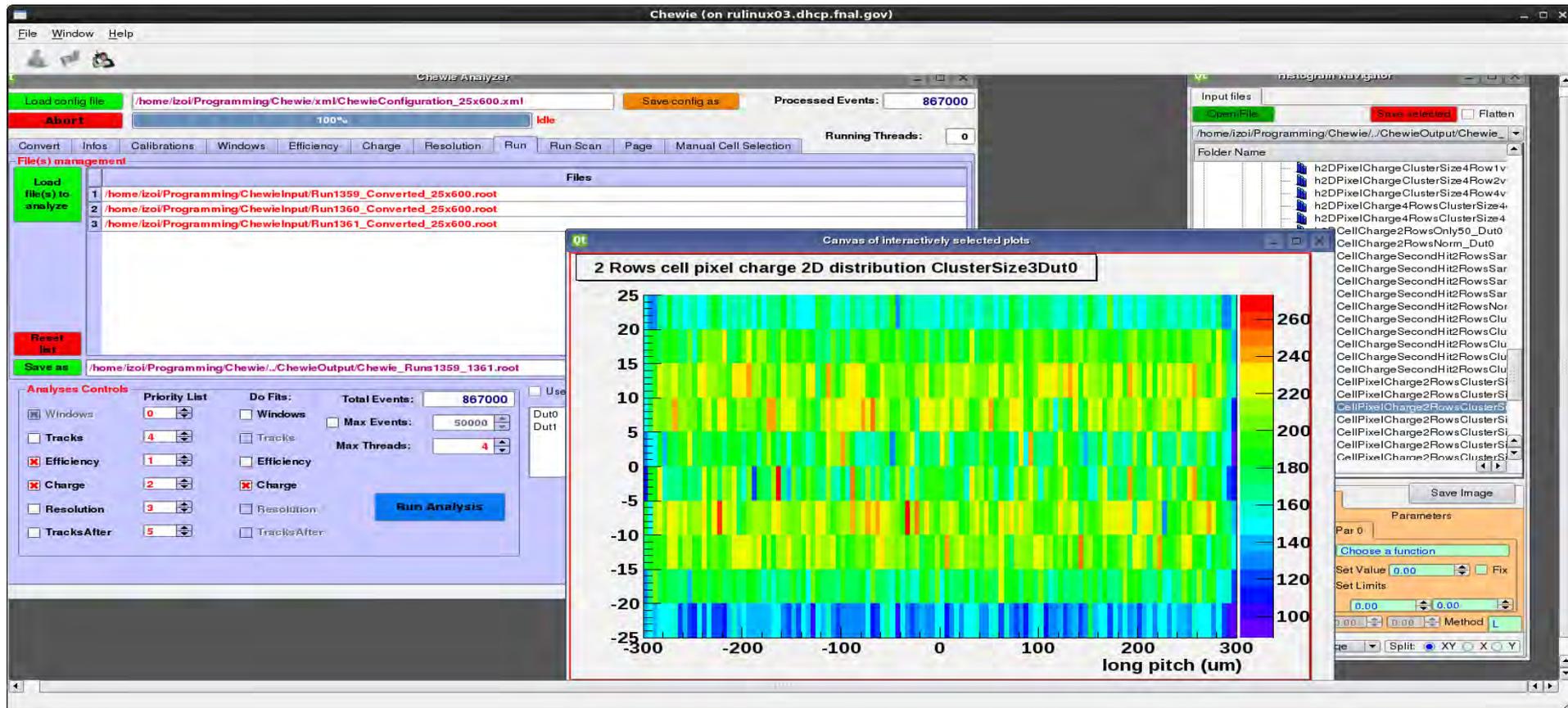
Monicelli

My first task was to complete the alignment of the DUTs in order to reconstruct the tracks.



Chewie

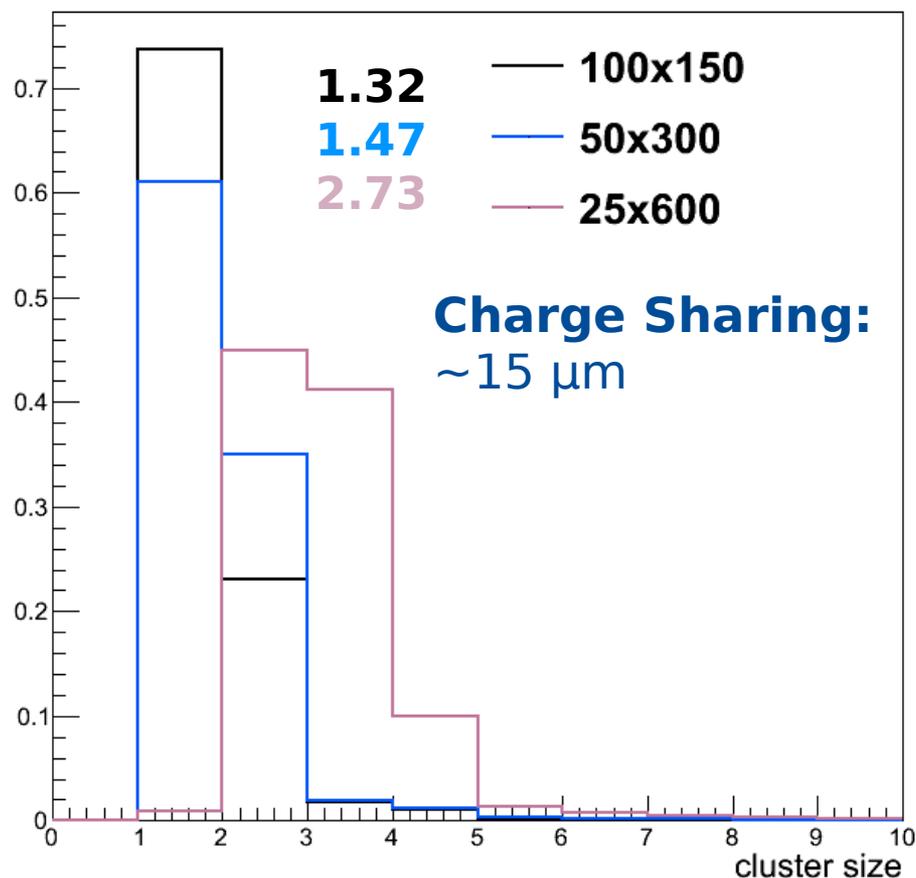
My second task is to modify the Chewie code in order to analyze the data obtained from the three different zones of the DUTs. I worked on the measurement of the collected charge and the resolution.



Cluster size

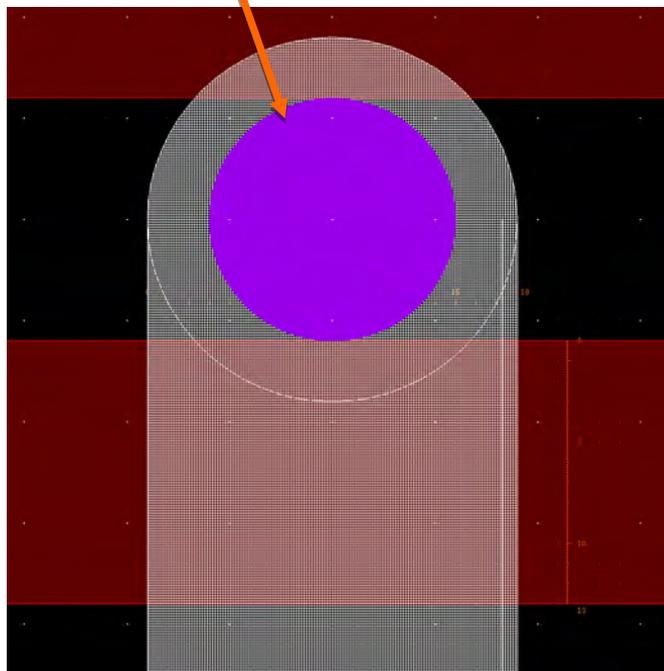
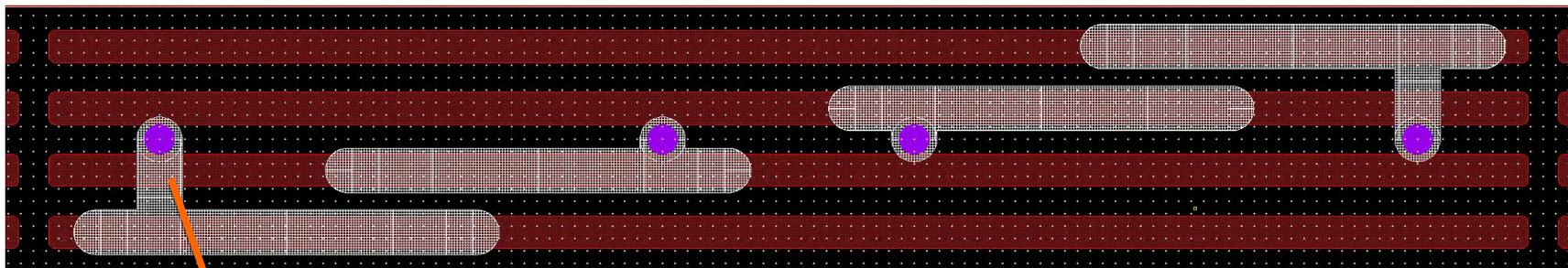
Cluster: collection of adjacent pixels with signal.

Test Beam FNAL, June15, Dut0=SPb2a V=120V



- **Cluster size increases as pixel pitch decreases.**
- 100 and 50 μm pitch pixel behave according to expectations.
- For the **25 μm** pitch:
 - No more single pixel clusters.
 - Several (10%) clusters of size 4
 - **maybe it is a consequence of the capacitors.**

25x600, closer look at the bonding

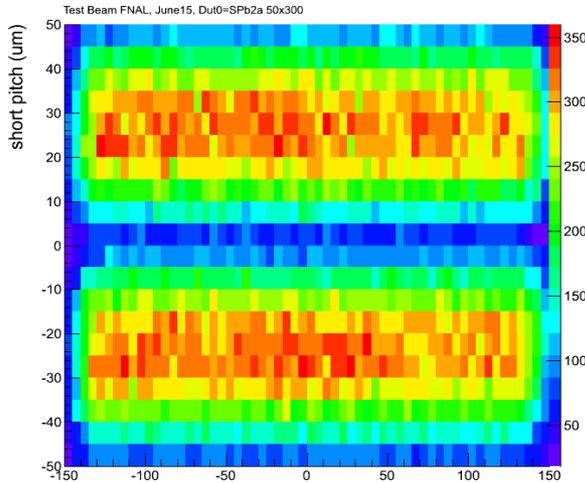


18 μm x 13 μm capacitance with a SiO_2 thickness of 900 \AA results on ~ 85 fF.

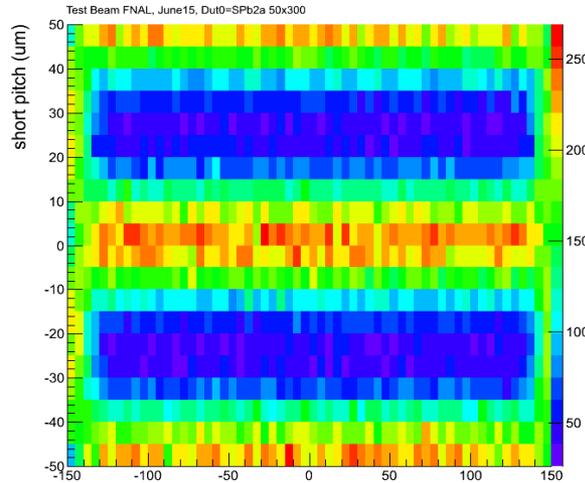
This capacitor can contribute to:

- capacitive load for the preamplifier
- spurious charge sharing between adjacent pixels

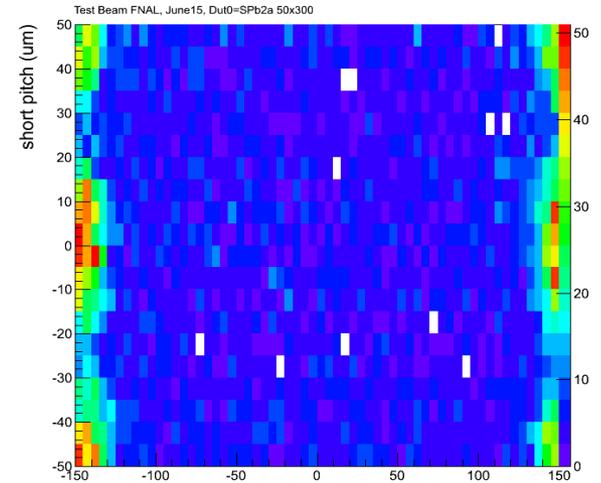
50x300 – Number of Clusters



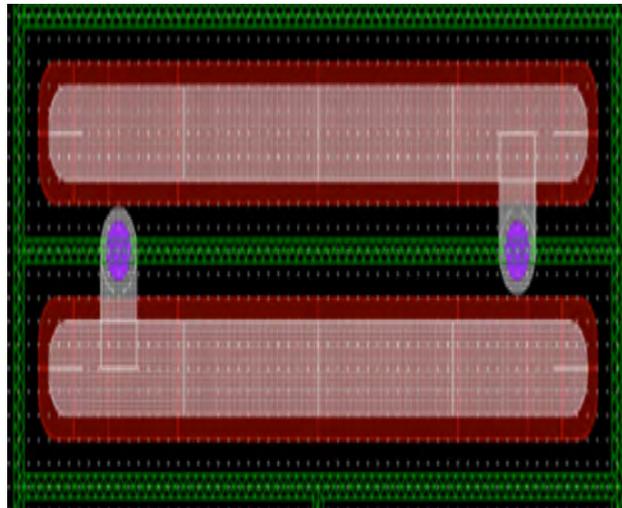
Size 1



Size 2



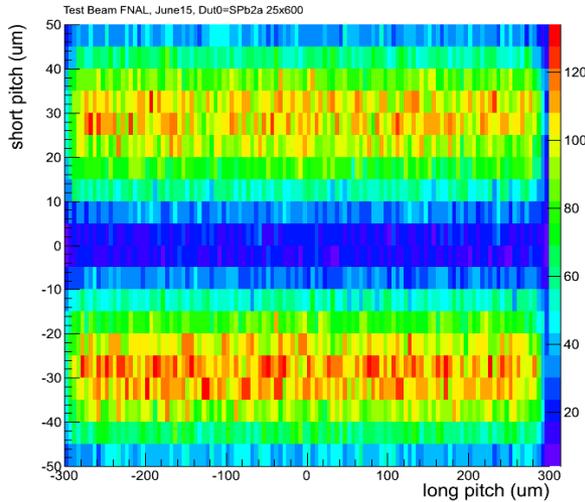
Size 3



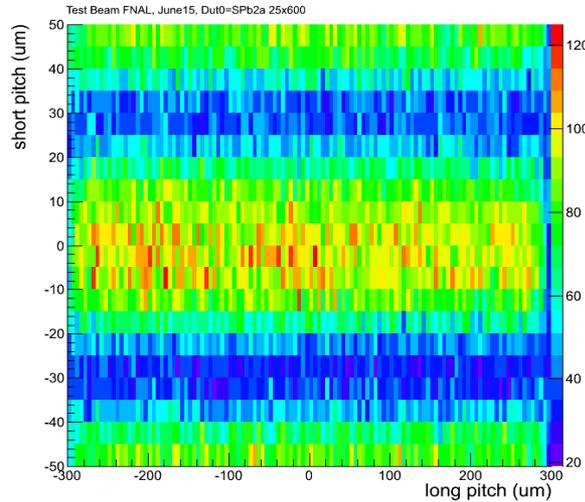
- **Size 1:** track is pointing at the center of the pixel.
- **Size 2:** edge between two adjacent pixels.

Pixels behave in the same way.

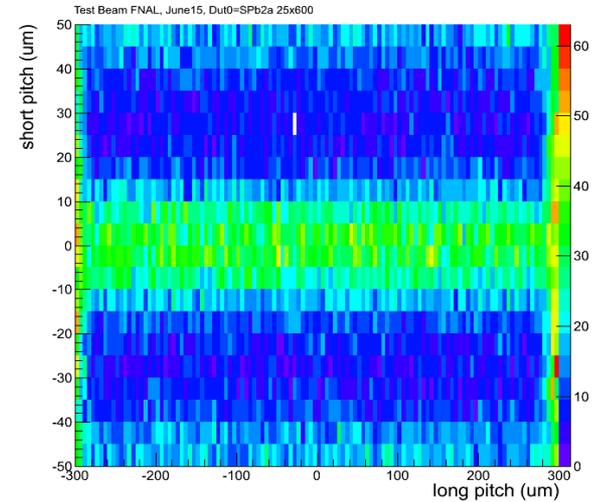
25x600 – Number of Clusters



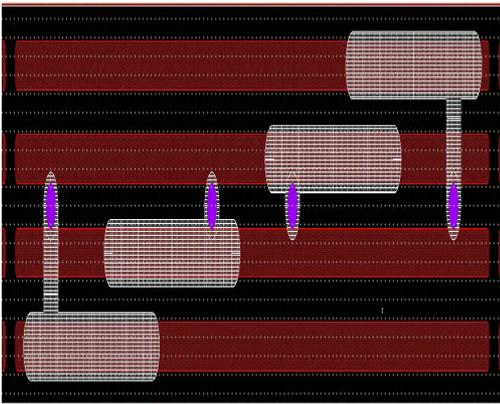
Size 2



Size 3



Size 4

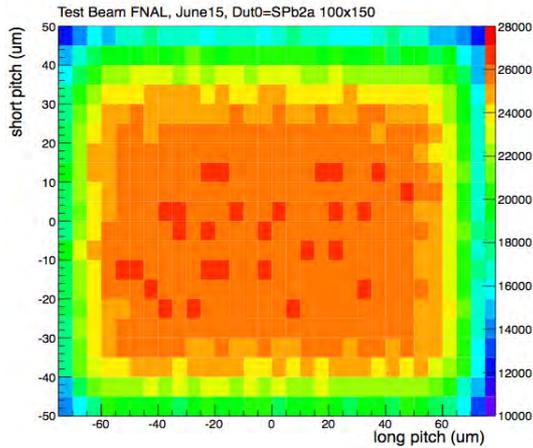


- **Size 2:** track is pointing to the top and bottom regions of the 4 cells.
- **Size 3:** center of the region of the 4 cells structure.
- **Size 4:** edge between the second and third row.

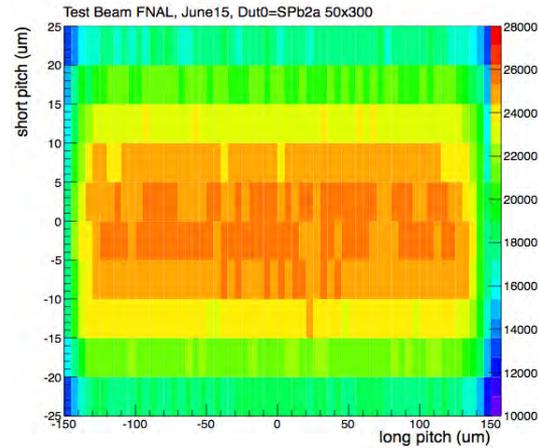
Pixels behave in different ways.

Pixel and Cluster Charge Map

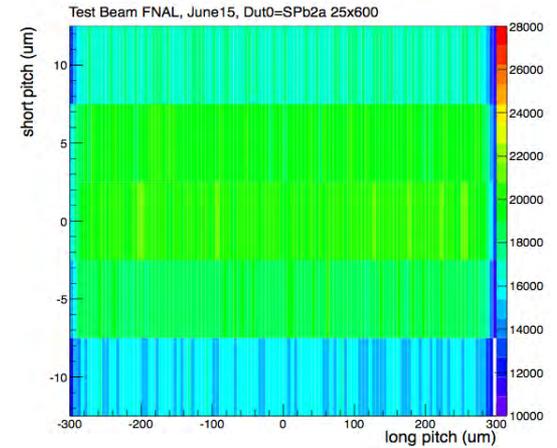
100x150



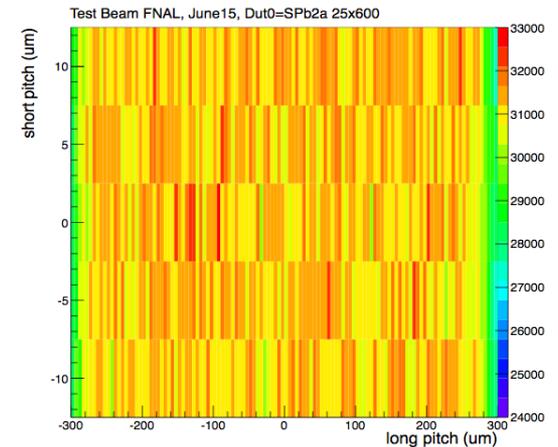
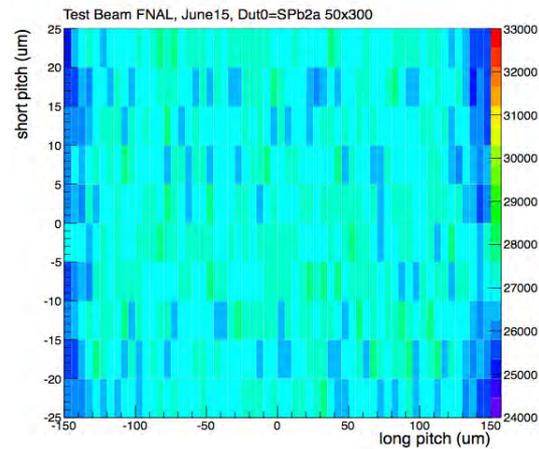
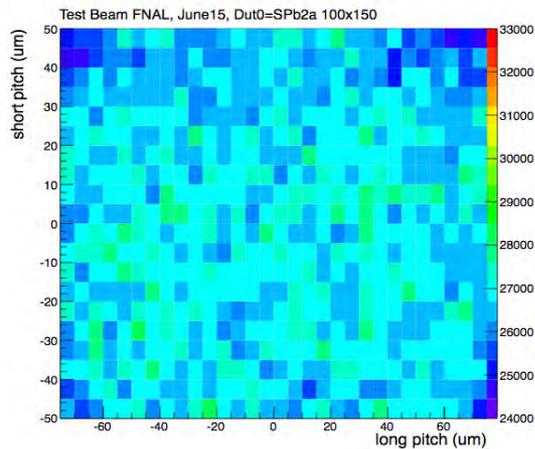
50x300



25x600

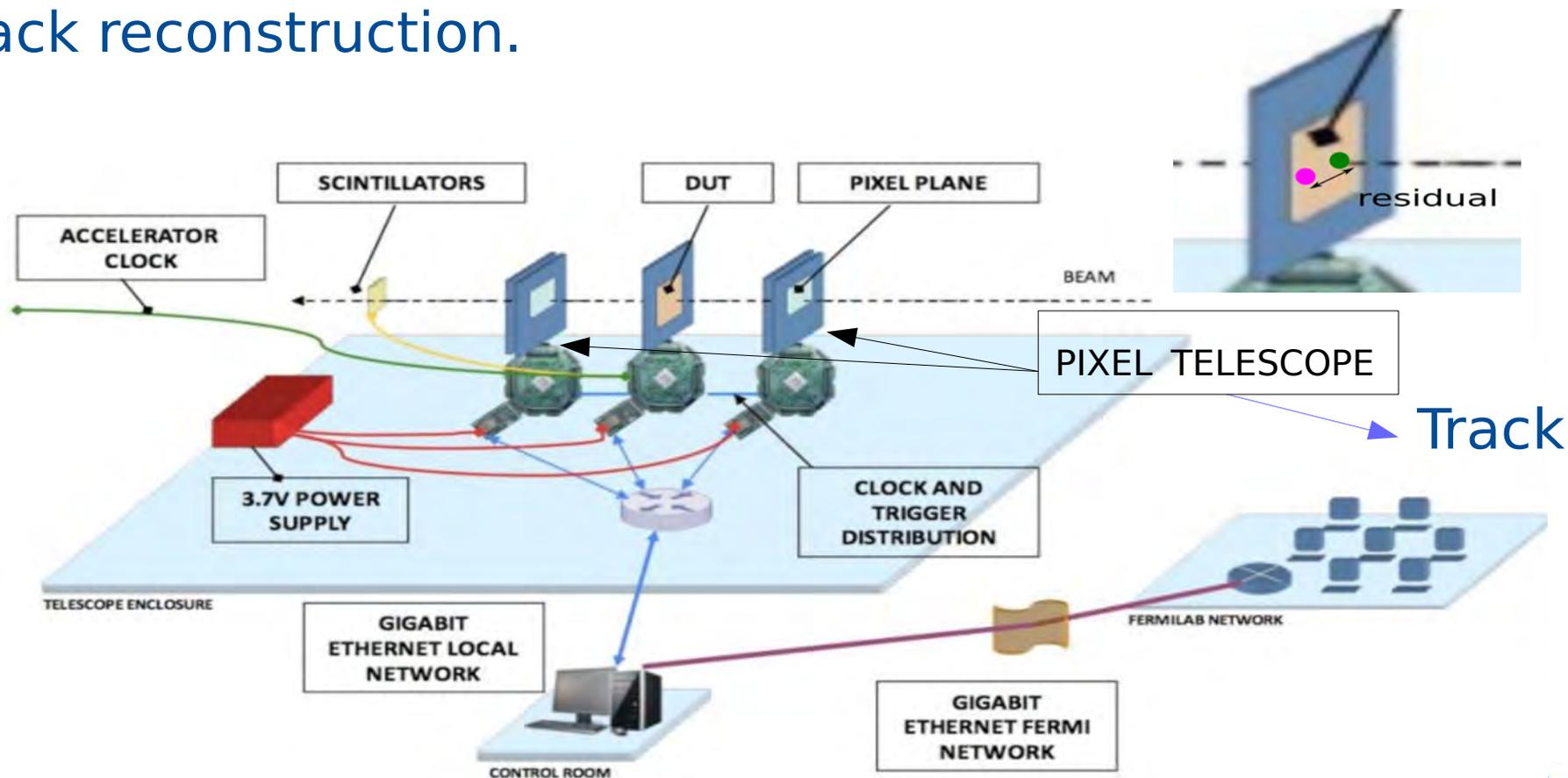


Always Charge Sharing



Spatial Resolution

- Spatial resolution is calculated using the **residuals**.
- A residual is the difference between the **measured impact point** and the **predicted impact point** from the track reconstruction.



Spatial Resolution

- We calculate the measured impact point with two different algorithms:

Center of mass

Asimmetry fit

- The resolution is quantified using the sigma of a gaussian fit on the residuals distribution.
In both cases we applied cuts on the collected charge and on the quality of the tracks.

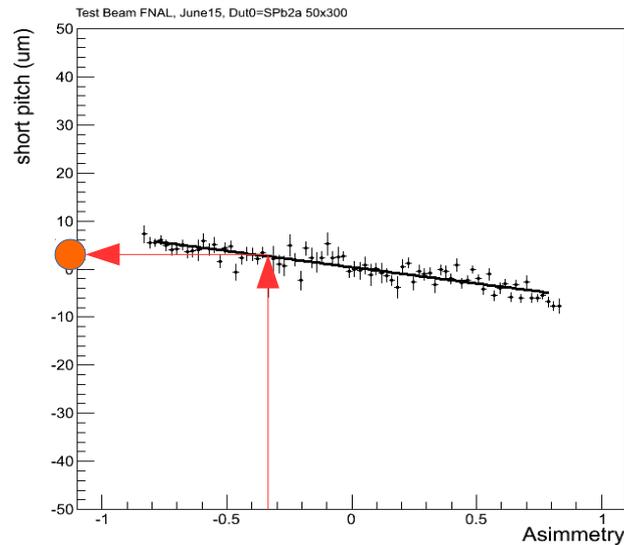
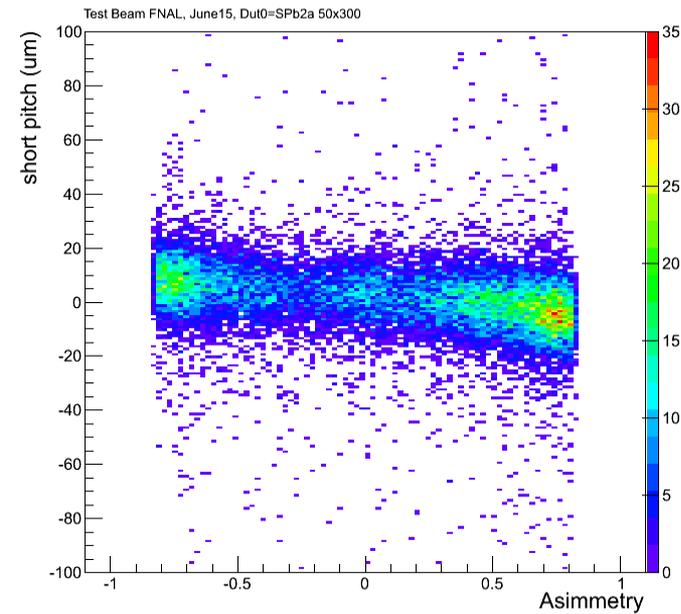
Asimmetry

Q_{up}

Q_{down}

size 2

$$\text{asimmetry} = \frac{Q_{down} - Q_{up}}{Q_{down} + Q_{up}}$$

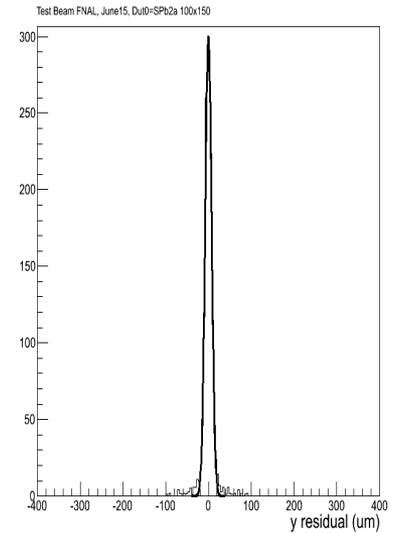
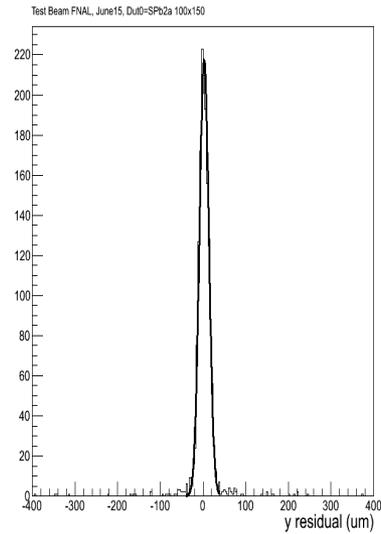
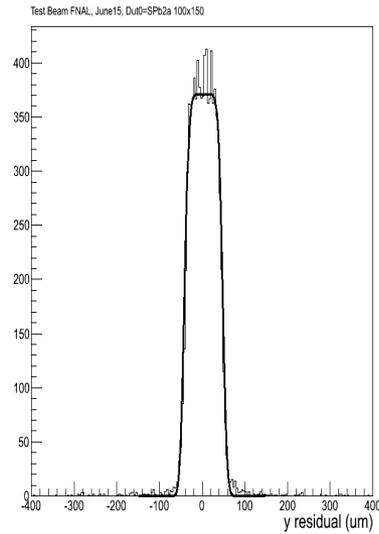
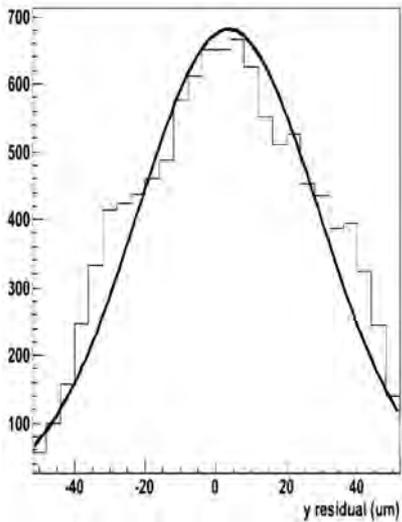


Linear fit on
asimmetry to
evaluate the
measured
impact point.

Resolution 100x150

Center of mass:

Asimmetry fit:



All Clusters

~24 μm

RMS without
tails

Size 1

~25.8 μm

Gaussian +
flat
distributions

Size 2

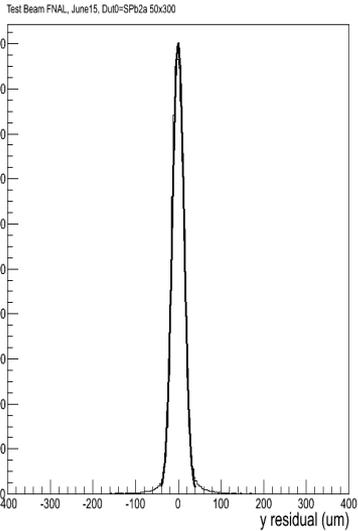
~11 μm

Size 2

7.5 μm

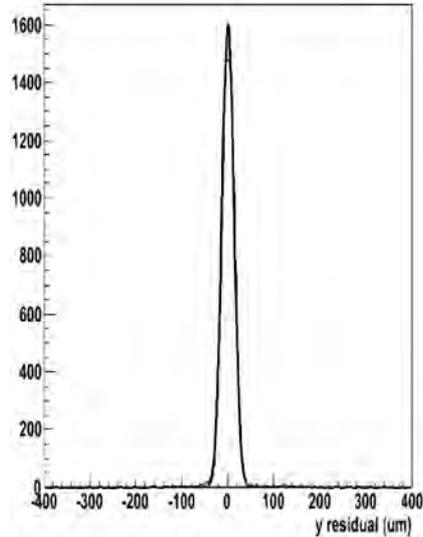
Resolution 50x300

Center of mass: **Asimmetry fit:**



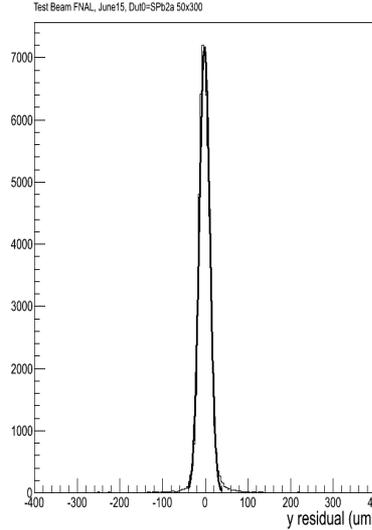
All Clusters

12.68 μm



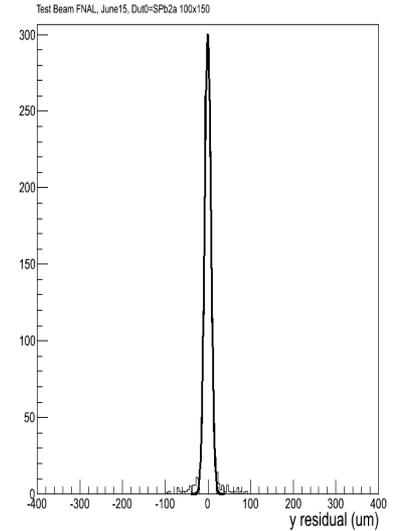
Size 1

12.96 μm



Size 2

11.25 μm



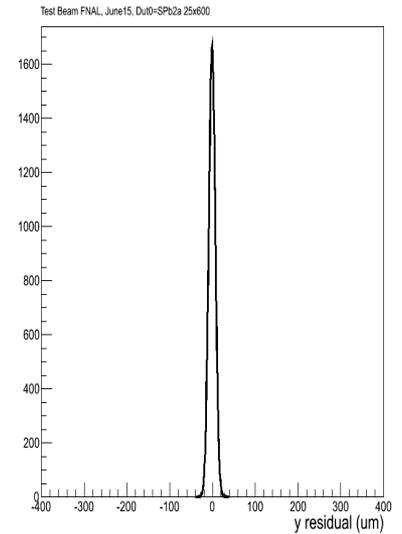
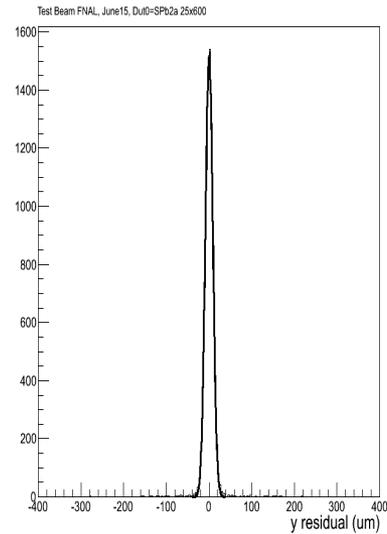
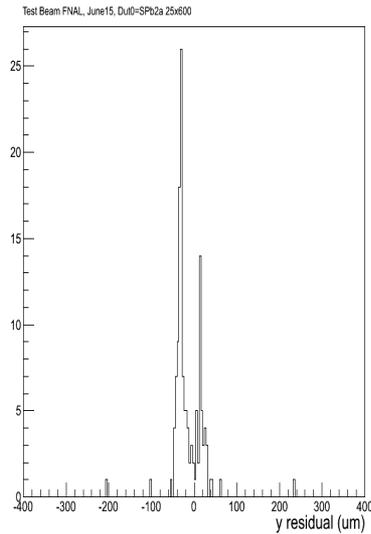
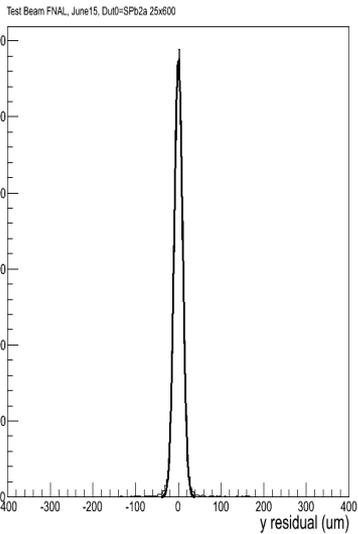
Size 2

7.8 μm

Resolution 25x600

Center of mass:

Asimmetry fit:



All Clusters

Size 1

Size 2

Size 2

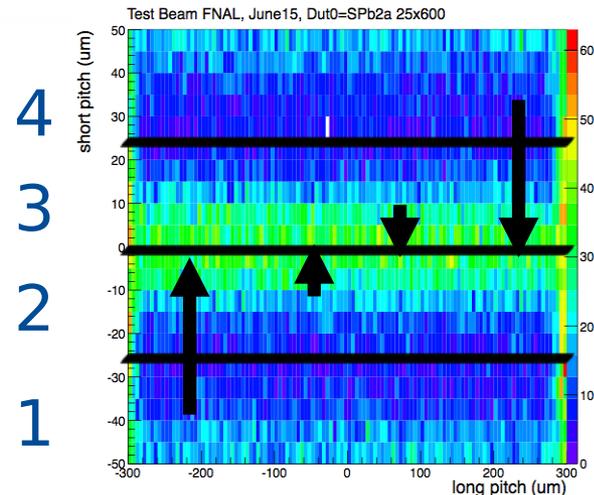
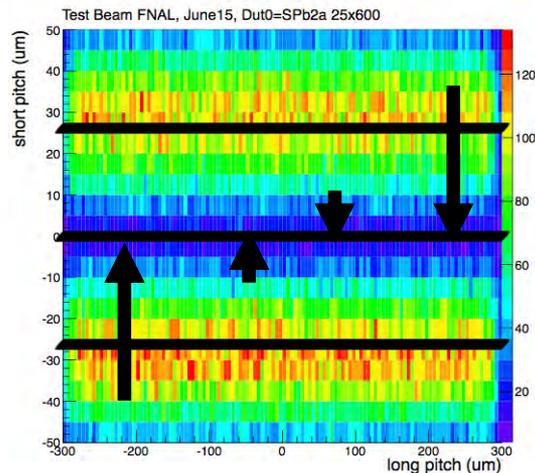
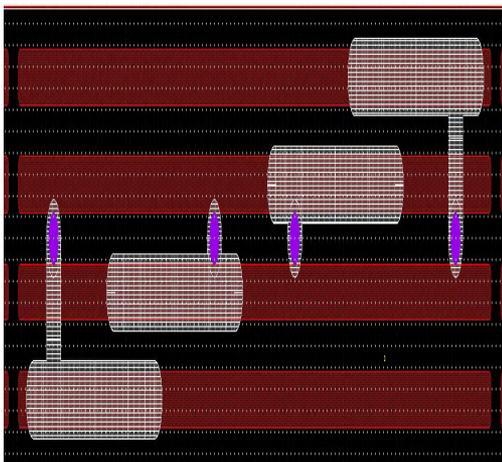
9.89 μm

Negligible
population.

8.78 μm

7.4 μm
Mean:-1.04 μm

25x600

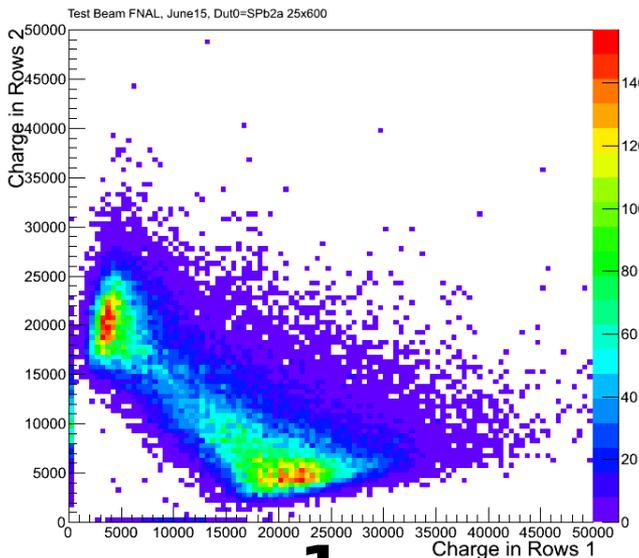


size 2

size 4

Missing highest charge in row 2: Cluster of size 4

We are trying to estimate in a quantitative way the correlation between the charge in this two rows.

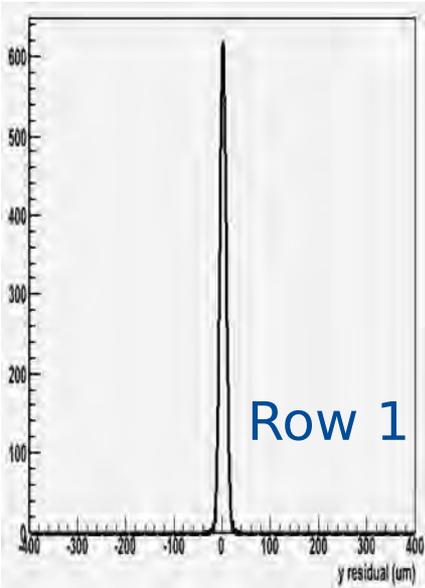


1

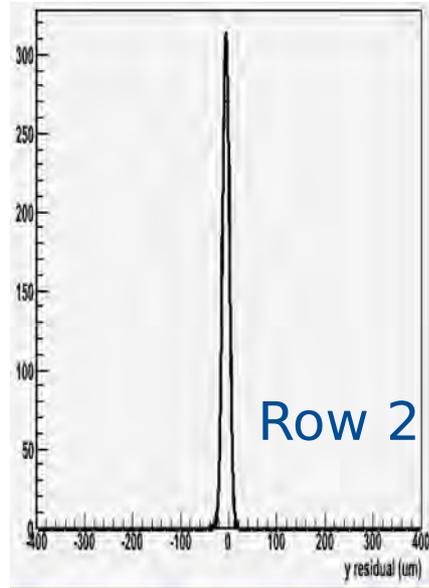
2

Resolution 25x600, Size 2

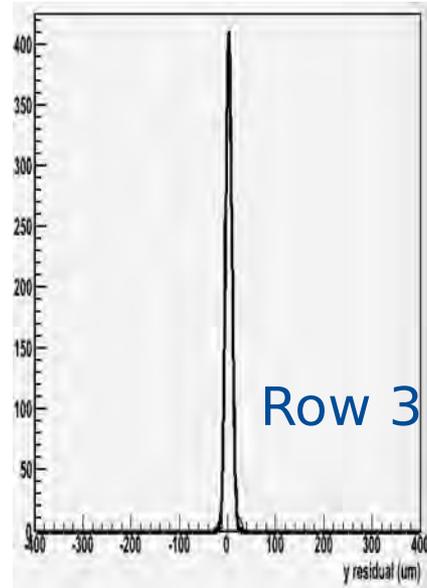
Residuals from asymmetry fit for the four rows:



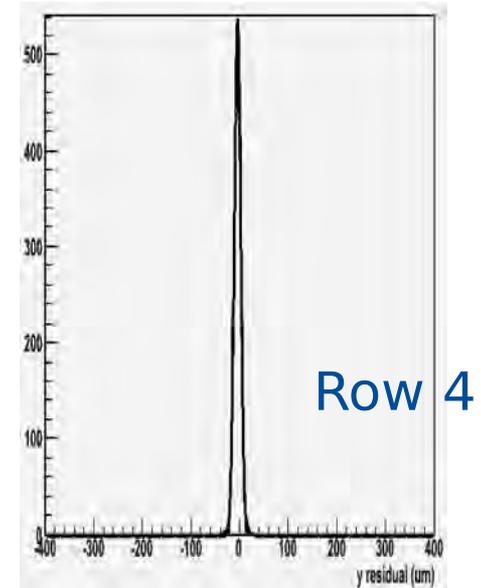
Mean: $1.9\mu\text{m}$
Sigma: $6.4\mu\text{m}$



Mean: $-5.9\mu\text{m}$
Sigma: $6.9\mu\text{m}$

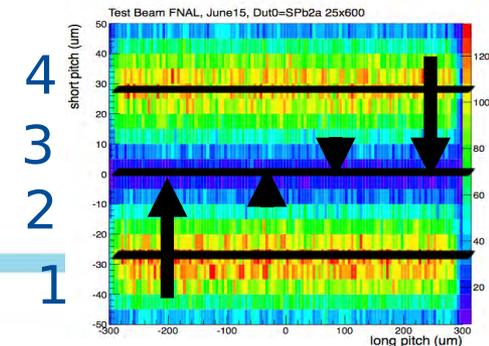


Mean: $2.8\mu\text{m}$
Sigma: $6.4\mu\text{m}$

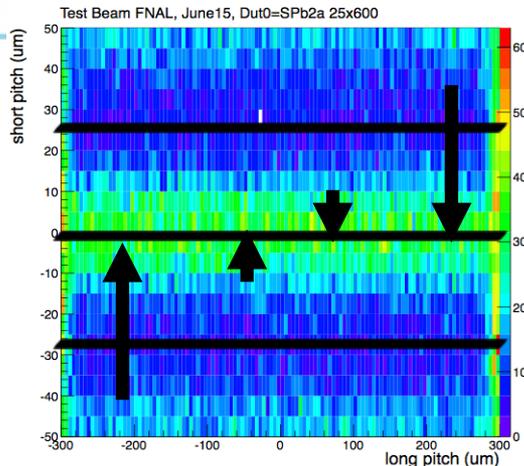
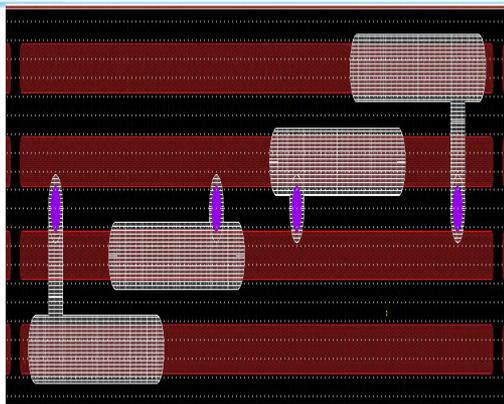


Mean: $-4.3\mu\text{m}$
Sigma: $6.6\mu\text{m}$

- The gaussian distribution for the residuals of size 2, calculated from the asymmetry fit, is the sum of these 4 gaussians.
- Gaussians are not centered in zero because of the asymmetric behavior of the pixel 1(4) and 2(3).

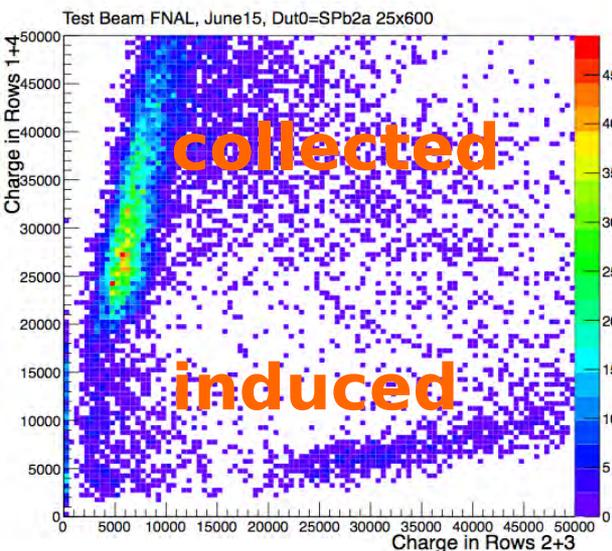


25x600

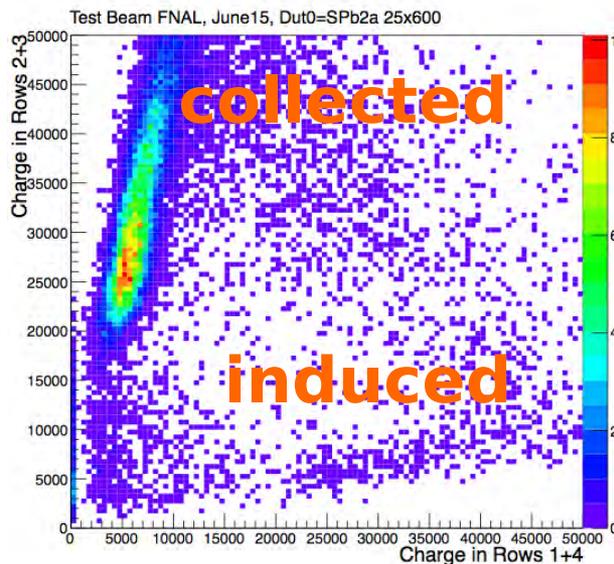


4
3
2
1

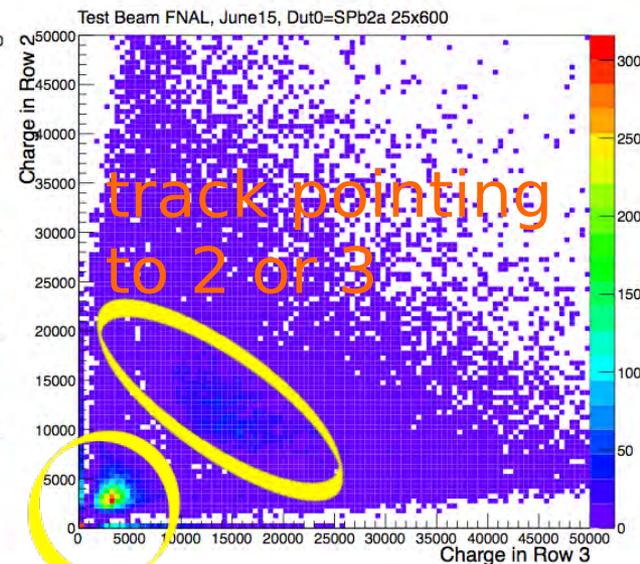
Clusters of size 4



track is pointing to 1 or 4



track is pointing to 2 or 3



track is pointing to 1 or 4

Conclusions and plans

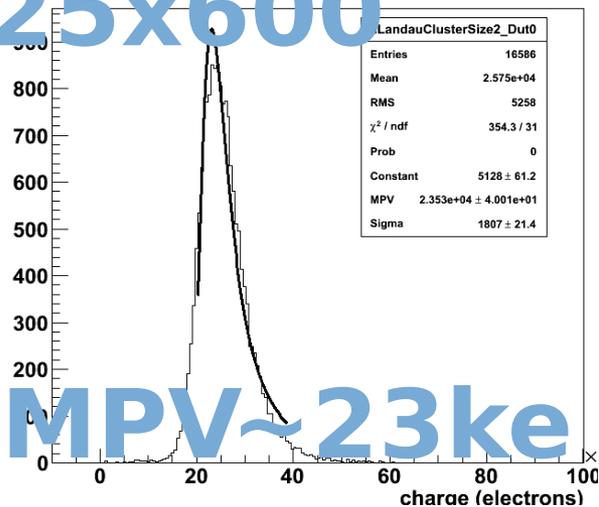
- The devices are fully efficient independently of the pitch.
 - Cluster size varies with the pitch as expected, except for 25x600.
 - We are working to understand the impact of the extra capacitance.
 - We are working on the corrections to be applied.
 - Calculate the telescope resolutions.
 - Calculate the errors on the resolution.
-
- After this experience I've learned more about the use of ROOT.
 - I studied pixel detector and I have a better understanding on the track reconstruction.
 - I learned how to analyze data on a prototype.

•Questions?

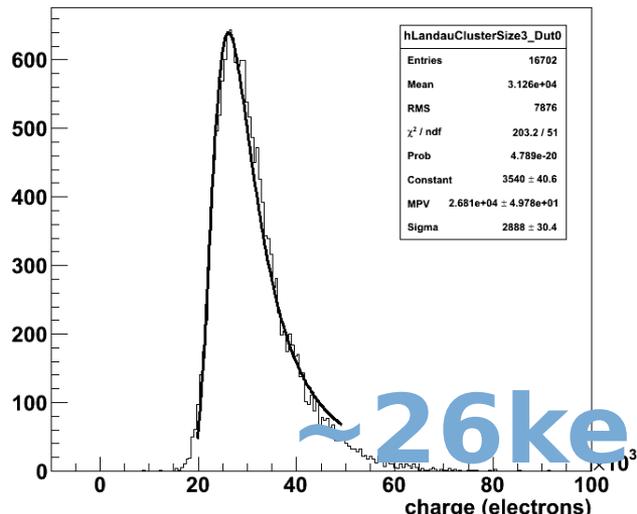
Thank you

Cluster charge distributions

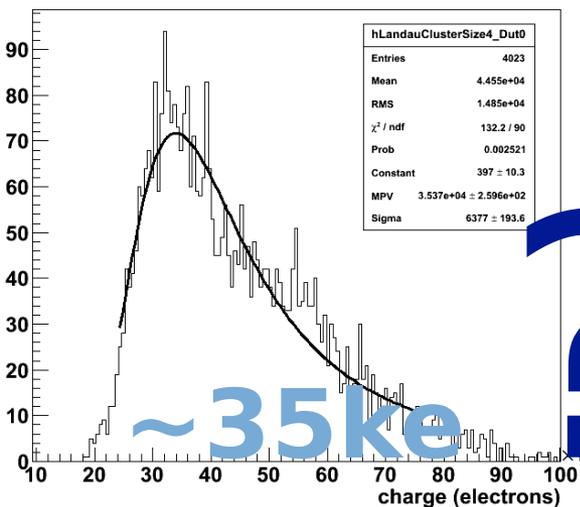
25x600



MPV ~ 23ke



~ 26ke



~ 35ke

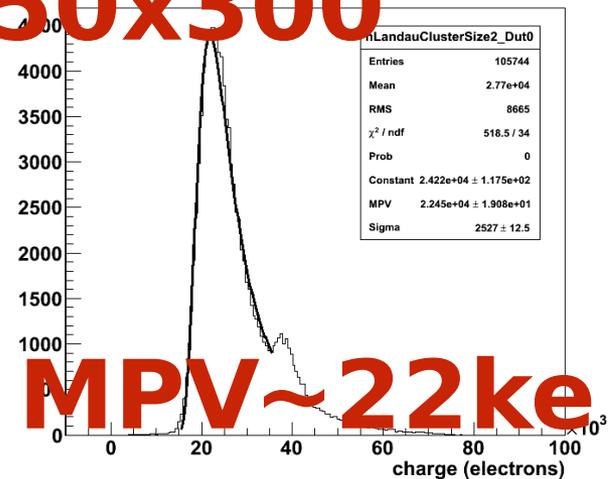


size2

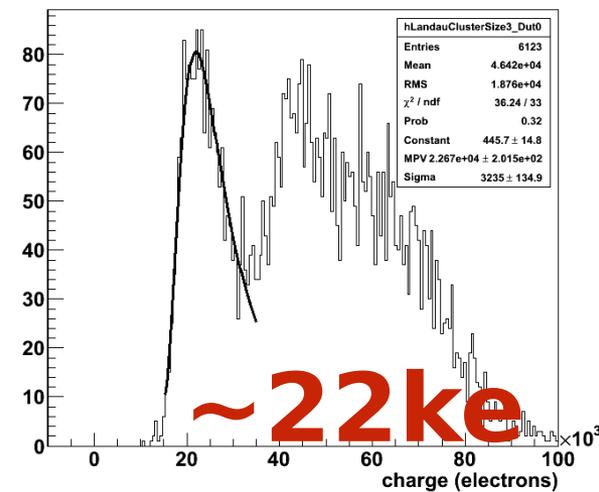
size3

size4

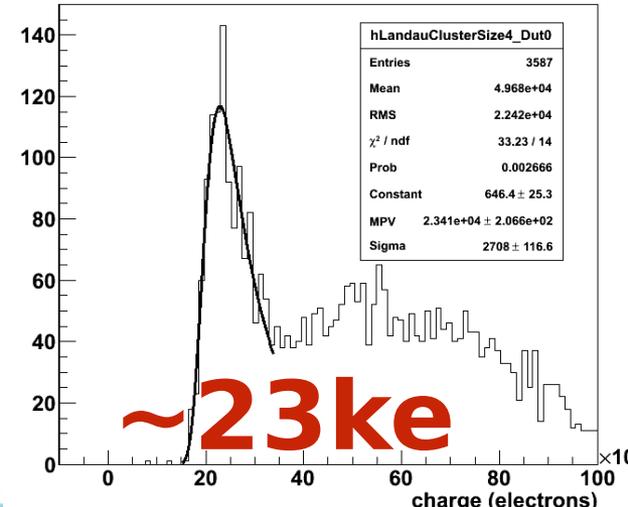
50x300



MPV ~ 22ke



~ 22ke

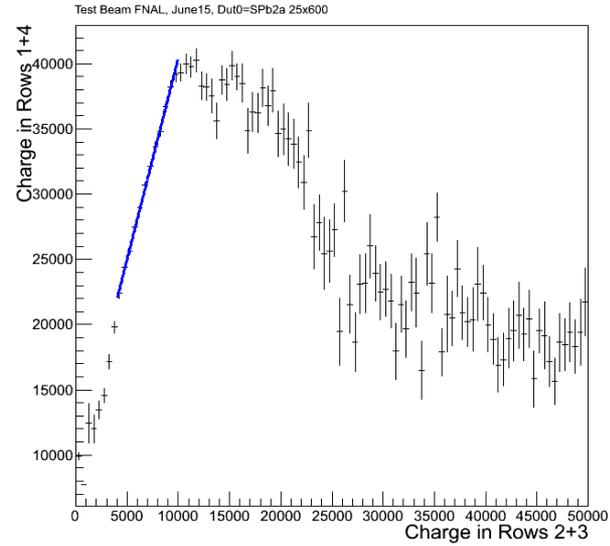
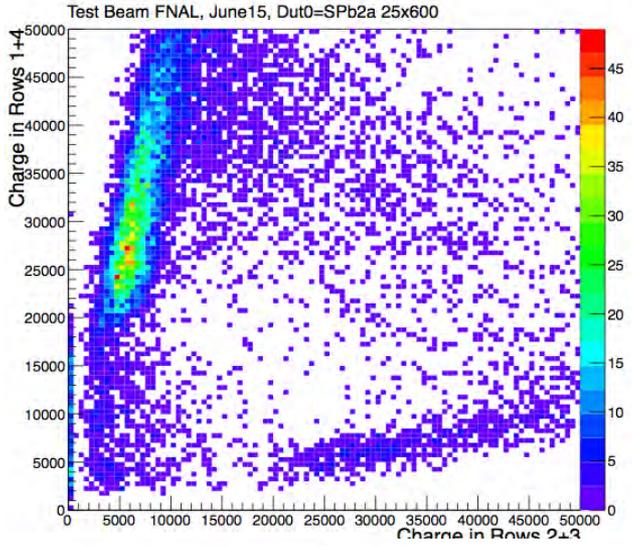


~ 23ke

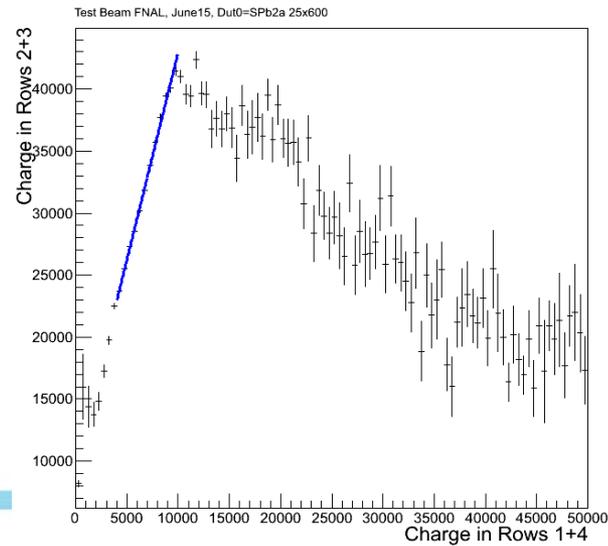
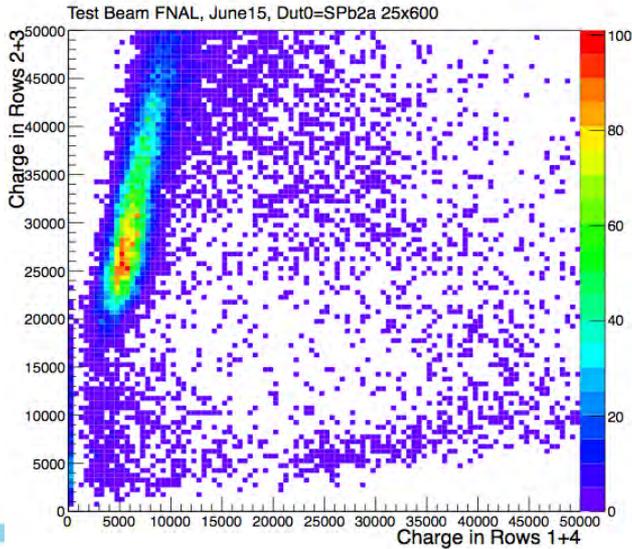
•Questions?

Thank you

25x600



Slope 3.08



Slope 3.33

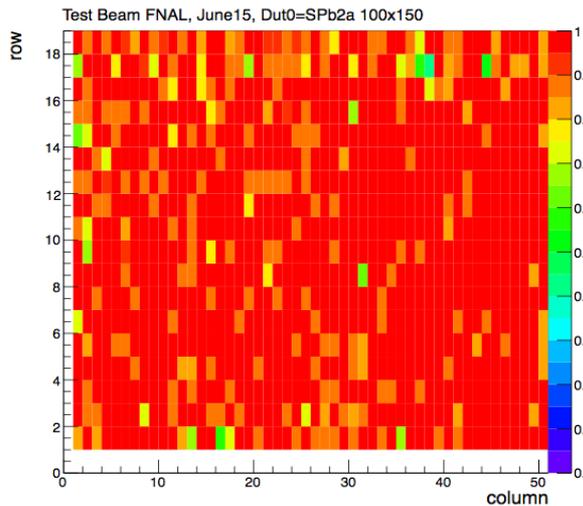
Efficiency

- Efficiency is computed excluding first and last row/column.

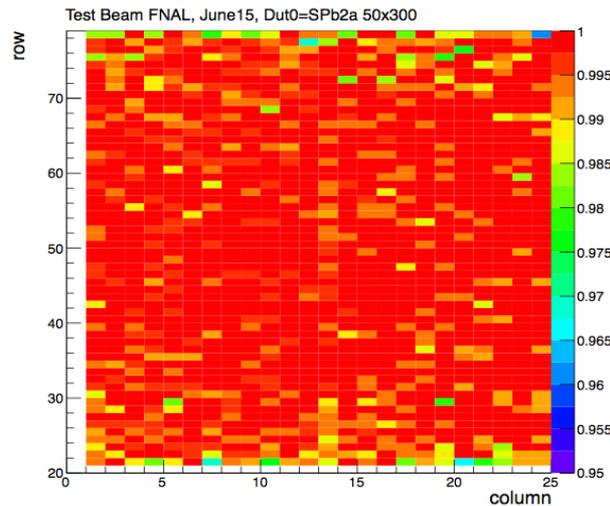
100x150

50x300

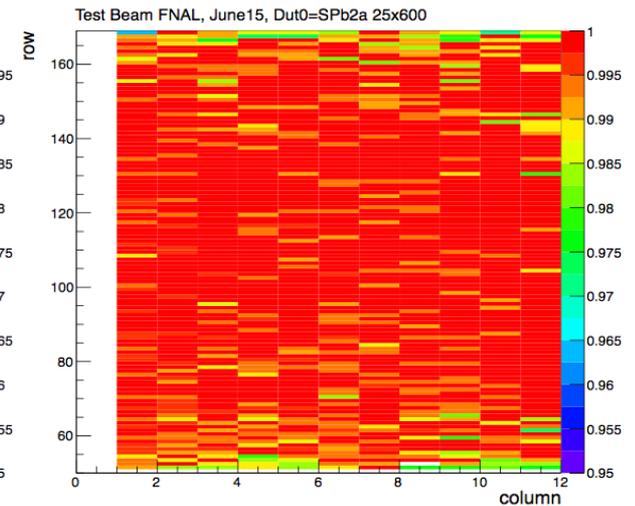
25x600



99.75 %

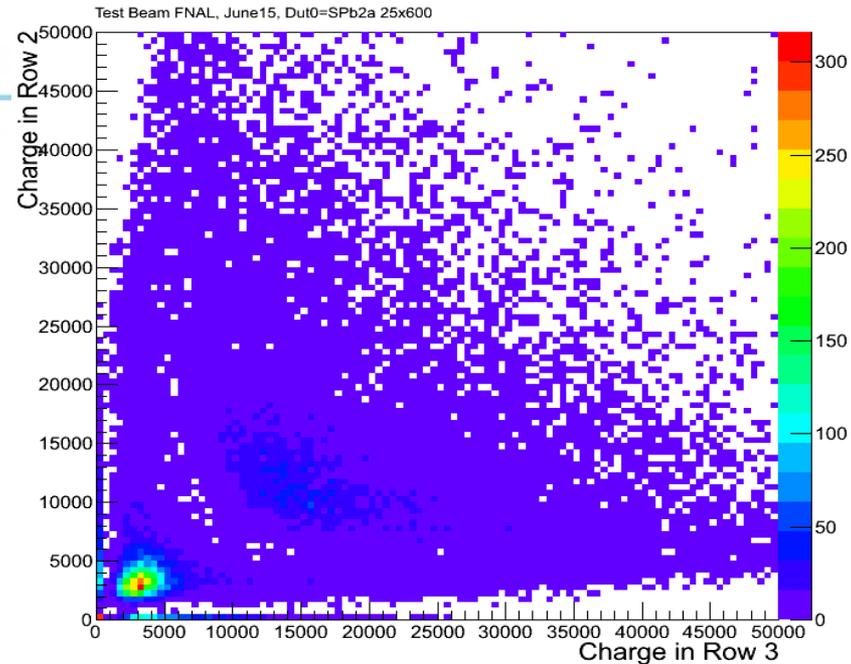
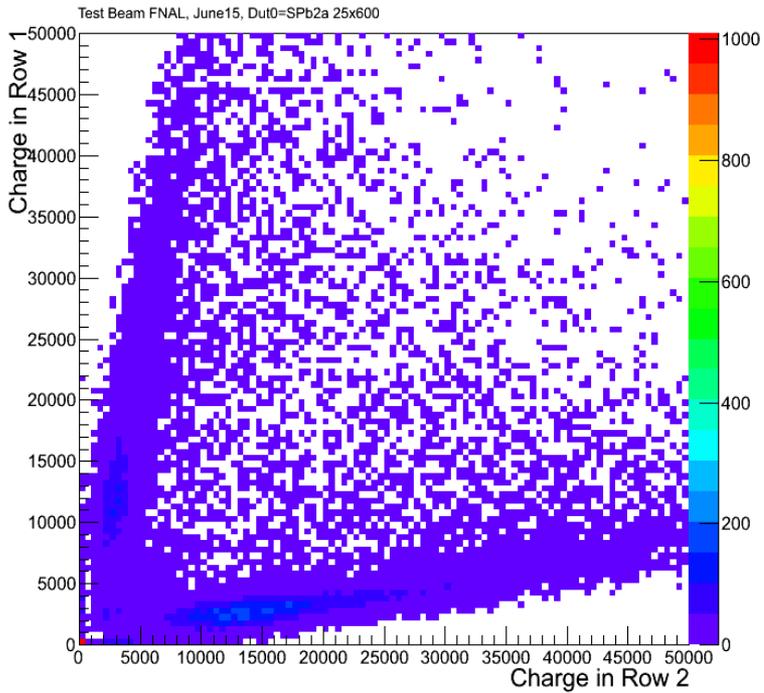


99.72 %

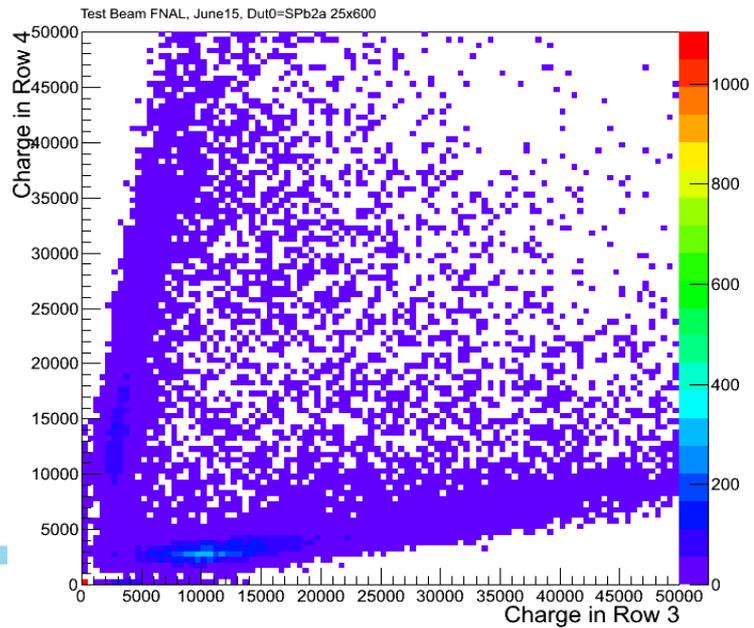


99.58 %

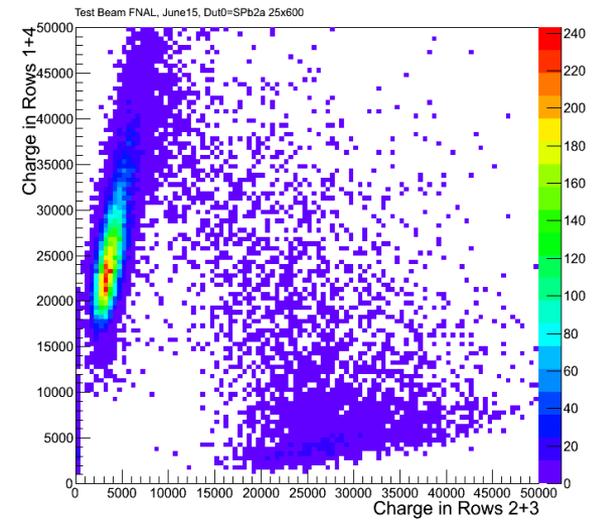
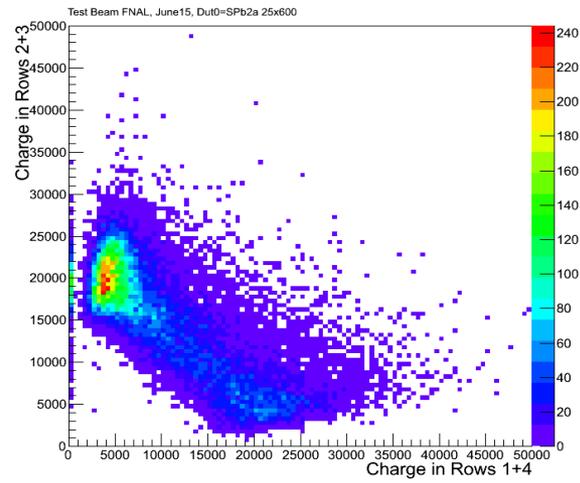
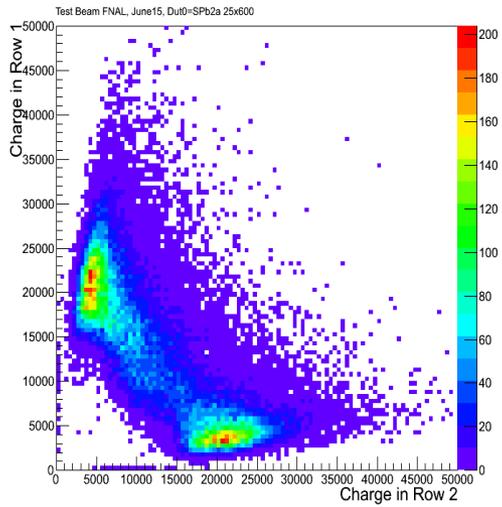
Back up



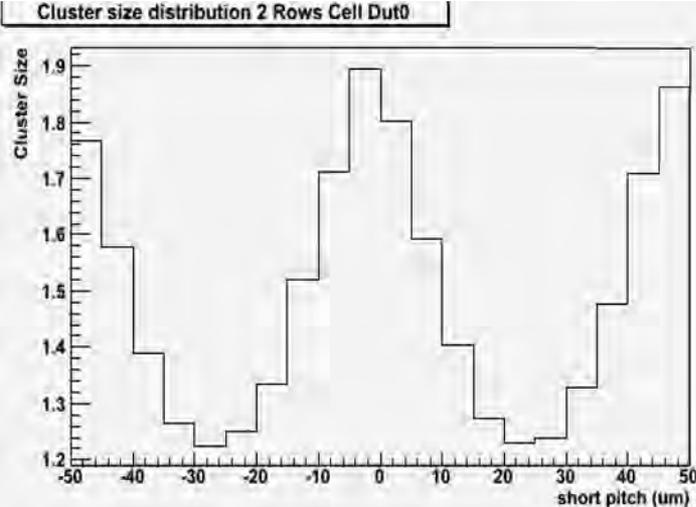
Size 4



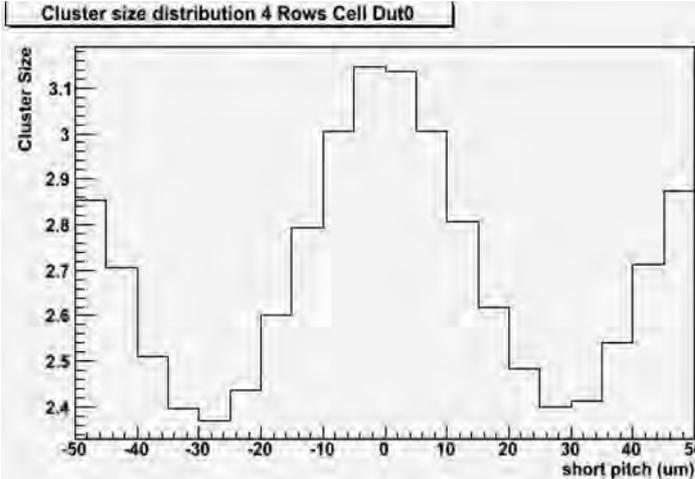
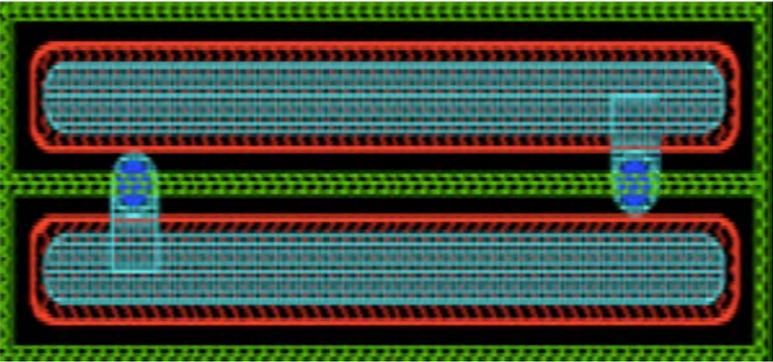
Size2



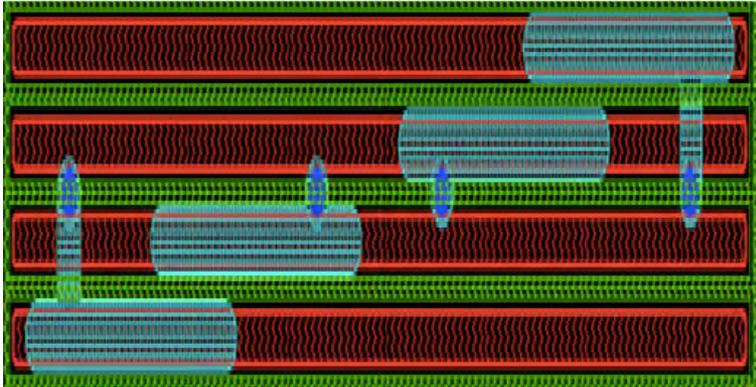
Summary



50x300



25x600

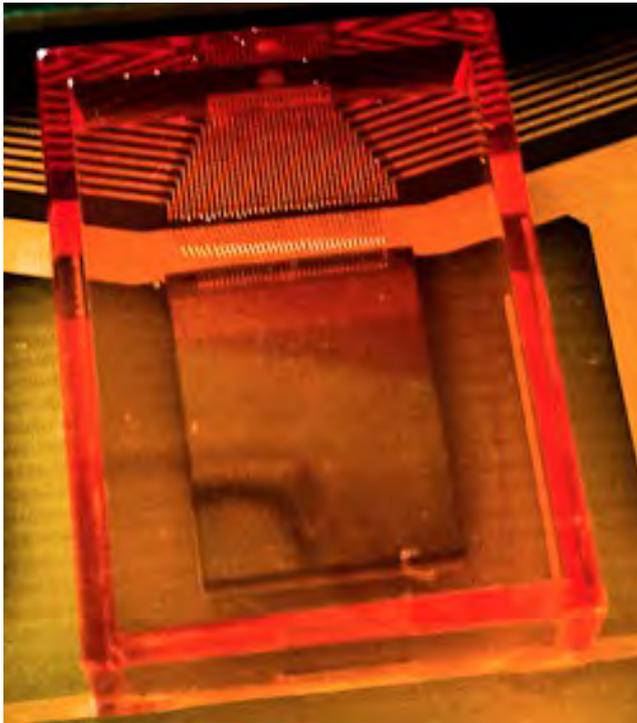


Future Plans

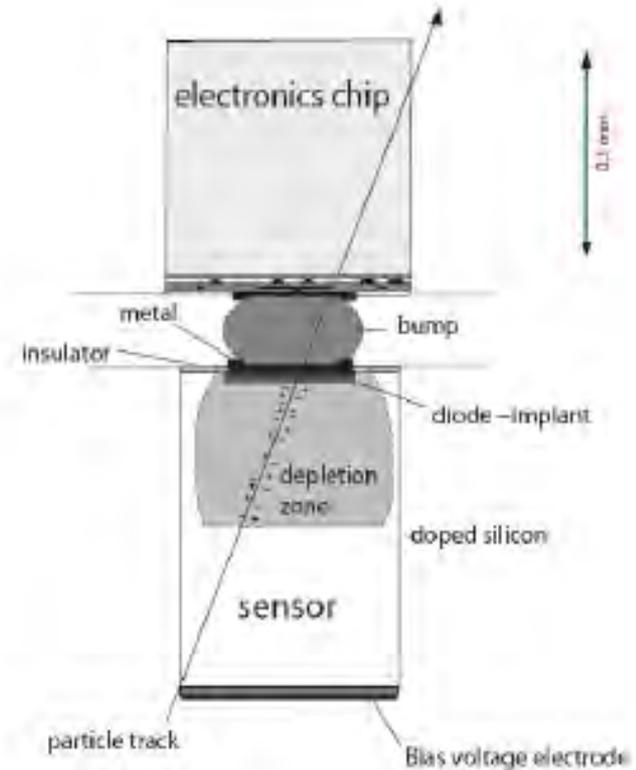
- Keep working on the analysis of the Small Pitch Sensors to have a better understanding of their behavior.
- In particular, I'll focus my studies on the **charge** and the **resolution**.

CMS Pixel Detector Design

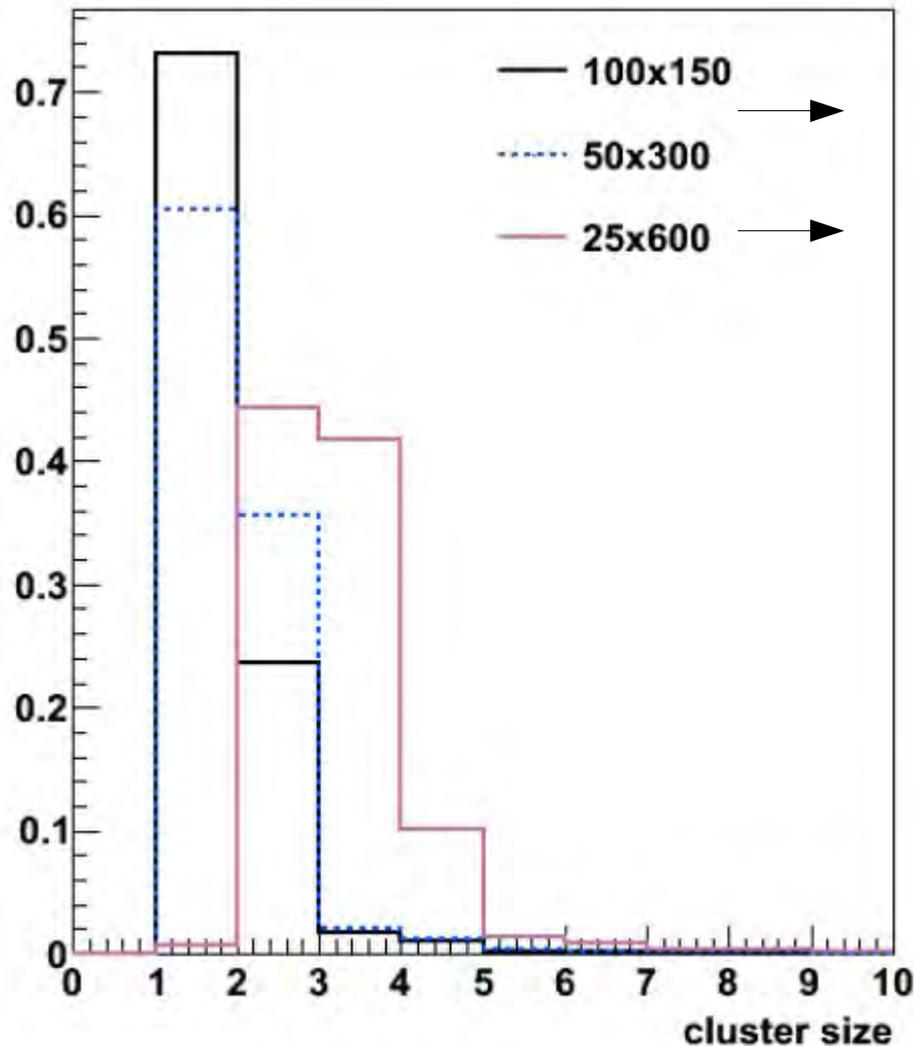
- 1 ROC has 4160 pixels
- Pixels of $100 \times 150 \mu\text{m}^2$ are disposed in 52 columns and 80 rows



- Each pixel is bump bonded to the ROC



Cluster Size



Size 1 and 2

Size 2, 3 and 4

Cluster: collection of adjacent pixels with signal.

Charge Sharing:
~15-20 μm